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A Review of Thermal Energy Storage Using Various Phase Change Materials

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***Abstract*: Solar radiation is one of the most prospective sources of energy. However, the large utilization of this form of energy is possible only if the effective technology for its storage can be developed with acceptable capital and running costs. Latent heat storage is one of the most efficient ways of storing thermal energy which provides much higher storage density, with a smaller temperature difference between storing and releasing heat. One of potential techniques of storing solar energy is the application of phase change materials (PCMs). There are large numbers of PCMs that melt and solidify at a wide range of temperatures, making them attractive in several applications. This paper reviews the different phase change materials for storing thermal energy. This work summarizes the investigation and analysis of the available thermal energy storage systems incorporating PCMs and looks at the state of art of thermal energy storage systems, utilizing PCM operating with small temperature differences, such as various PCMs like paraffin waxes, myristic acid, which possesses moderate thermal energy storage density but low thermal conductivity and require large surface area.**

***Keywords*: Solar energy, Latent heat storage, PCM, paraffin waxes, myristic acid**

1. Introduction

Energy storage plays important roles in conserving available energy and improving its utilization. Solar energy is available only during the day, and consequently, its application requires

Efficient thermal energy storage (TES), so that the excess heat collected during sunshine hours may be stored for later use during the night. Therefore, the successful application of solar energy depends to a large extent on the method of energy storage used. TES is a technology which can reduce the total energy consumption and may involve sensible heat storage (storing of energy by heating or cooling), latent heat storage (by melting or vaporizing or solidifying or liquefying) or a combination of both. The latent heat method of storage has attracted many applications, as will be discussed in this review paper.

However, practical difficulties usually arise in applying the latent heat method due to the low thermal conductivity, density change, and stability of properties under extended cycling. In this present work, latent heat refers to the latent heat of melting, as other phase changes, such as evaporation, are not practical due to the large volume change associated with it. In accordance with the topic, this paper provides a review of studies dealing with TES using PCMs and classification of PCMs.

2. Classification of PCMs

PCMs absorb or release a considerable amount of energy during their transition from one phase to another phase.

- Gas-liquid PCMs
- Solid-liquid PCMs
- Solid-gas PCMs
- Solid-solid PCMs

For using water or any other carrier-liquid, solid-liquid PCMs (that are insoluble in the given liquid) are convenient to use. The solid-liquid PCMs can be further categorized into the following types.

- Organic PCMs
- Inorganic PCMs
- Eutectic PCMs

A. Inorganic PCMs

It can be further divided into the following

Salt Hydrates:

Salt hydrates are inorganic compounds combined with water in a definite ratio to form a characteristic crystalline solid. Salt hydrates undergo dehydration (or hydration) to some degree during the phase change process.

Metallics:

Metallics have high heat of fusion per unit volume and high thermal conductivity. However, they are unfavorable for use as a PCM because of high density (and low heat of fusion per unit mass).

B. Organic PCMs

It undergoes phase change without degradation of their latent heat of fusion. They also crystallize with no supercooling (i.e. the process of lowering the temperature of a liquid or a gas below its freezing point without it becoming a solid) and are usually non-corrosive. Organic PCMs are divided into the following two types:

Paraffins:

Paraffins consist of straight chain alkanes (alkanes are organic compounds consisting of only carbon and hydrogen in single bonds). The values of melting point and latent heat of

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fusion increase with increase in carbon number of the alkane.

Non-Paraffins:

Non-paraffins include a wide range of organic compounds including fatty acids, alcohols, glycols, and esters.

C. Eutectic PCMs

A eutectic is a minimum-melting composition (mixture) of two or more components that usually melts and freezes without any segregation.

3. Different PCMs and its properties

A. Paraffin

Earlier studies have already established the thermos physical properties of the organic paraffin as reported below by Table 1.

Table 1
Thermal physical properties of the organic paraffin

Thermo physical	Magnitude	Properties Units
Melting/ solidification T	300.7	K
Latent heat fusion	206	kJ/kg
Thermal conductivity S-L	0.18 /0.19	W/m K
Specific heat S-L	1.8 / 2.4	kJ/kg K
Density	789 / 750	kg/m^3

Khyad et al. established that commercial paraffin waxes, which melt around 55°C, have been studied most. Here we have similarly employed three commercial waxes having melting temperatures of 44, 53 and 64°C with latent heats of 167, 200 and 210 kJ/kg, respectively, in the same storage unit to improve its performance. The normal paraffin of type CnH2n+2 are the family of saturated hydrocarbons with almost similar properties. It is proved that higher the value of n, the higher is the melting temperature and latent heat of fusion. For example, paraffin wax consists of a mixture of mostly straight chain n-alkanes CH3–(CH2)–CH3. The crystallization of the (CH3)-chain releases a large amount of latent heat. Both the melting point and latent heat of fusion increase with chain length.

Paraffin waxes the most commonly used commercial organic heat storage PCM. It consists of mainly straight chain hydrocarbons having melting temperatures ranging between 23 and 67°C. Paraffin qualifies as heat of fusion storage materials due to their availability in a large temperature range. But, due to cost consideration, only technical grade paraffin may be used as PCMs in latent heat storage systems. Paraffin is safe, reliable, predictable, less expensive and non-corrosive.

Khyad et al. performed thermal cycling tests on three paraffin waxes of different melting temperatures indicated as type A (melting point 58–60 °C), type B (60–62 °C) and type C (54 °C). For type A and type B paraffin, number of cycles of operation performed was 600 while type C was tested for 1500 cycles. The changes in melting point and latent heat with increasing in number of cycles were significant for type A and B. However, type C paraffin wax was found most suitable for latent heat storage purpose on the basis of its stability even after 1500 cycles of operation.

A list of mentioned paraffin is given in Table 2 with a comparison of their melting point and latent heat of fusion. It can be noted that the most studied paraffin has melting temperature in the range of 45 °C to 60 °C. This paraffin was tested for thermal stability up to 1500 thermal cycles. Further, it can also be noted that paraffin does not show regular degradation in its thermal properties after repeated number of thermal cycles.

Table 2
Comparison of melting point and latent heat of thermal cycled paraffin

Paraffin	Melting point (°C)	Latent heat (J/g)	Thermal cycles
Paraffin (C22.2H44.1)	47.1	166	900
Paraffin (C23.2H48.4)	57.1	220	900
Paraffin wax53	53	184	300
Paraffin wax54	53.32	184.48	1500
Paraffin wax58–60	58.27	129.8	600
Paraffin wax60–62	57.78	129.7	600

4. Myristic acid

It was chosen as a novel PCM for this research due to the following favorable thermal, physical, kinetic, chemical, and economic properties:

A. Thermal properties

1. *Phase-transition temperature range:* The temperature range of interest was 50-60°C because it is well above atmospheric temperature in most areas (to ensure that the phase transition does not occur due to atmospheric heat), and low enough to reduce the cost of insulation. The melting point of myristic acid is 49-51°C.
2. *High latent heat of fusion:* The latent heat of fusion of myristic acid is 199 kJ/kg, which is high compared to the other PCMs in the temperature range considered.

B. Physical properties

1. *Density:* The density of myristic acid is 990kg/m3 which is comparable to that of water at 1atm. and 4°C (1000kg/m3). The density of water decreases on increasing temperature and attains a value of 990kg/m3 near the temperature range of interest. This property will be interesting to observe in the experiments to determine if density plays a role in clumping of myristic acid during solidification.
2. *Insolubility in water:* Myristic acid is insoluble in water. Thus, the physical properties of myristic acid will remain unchanged when added in water.

C. Kinetic properties

No supercooling: Myristic acid does not undergo supercooling because of self-nucleation.

Chemical Properties:

Non-toxic: myristic acid does not have any serious health hazards.

Economics:

Availability: Myristic acid occurs in nature in cow's milk, some fish oil, some seeds (e.g. coconut and palm kernel). Furthermore, it can also be manufactured using nutmeg. Myristic acid is also used as a food additive. Due to its availability and low health hazards, the cost associated with chemical safety precautions for myristic acid is low.

Myristic acid is a common saturated fatty acid with a molecular formula CH_3 (CH_2)12COOH its salts and esters commonly referred as myristates. According to Shrestha et al. experiment he concluded that the temperature range of myristic acid is (50-60ºC) and appropriate phase transition temperature range of 49-51ºC, high latent heat fusion of 199 kJ/kg and it is no supercooling, non-toxicity, and availability in nature.

5. Required properties of PCM

Amongst above thermal heat storage techniques, latent heat thermal energy storage is particularly attractive due to its ability to provide high-energy storage density and its characteristics to store heat at constant temperature corresponding to the phase transition temperature of phase change material (PCM). Selection of PCM is based on the application but the PCM to be use should possess Thermal physical, kinetics and chemical properties which are as follows

Thermal properties:
1. Suitable phase-transition temperature.
2. High latent heat of transition.
3. Good heat transfer.

Physical properties:
1. Favorable phase equilibrium.
2. High density.
3. Small volume change.
4. Low vapor pressure

Kinetic properties:
1. No super cooling.
2. Sufficient crystallization rate.

Chemical properties:
1. Long-term chemical stability.
2. Compatibility with materials of construction.
3. No toxicity.
4. No fire hazards.

Economics:
1. Abundant
2. Available
3. Cost effective

6. Conclusion

In the present paper, we had detailed study on PCM incorporation in thermal energy storage systems. The optimization of some parameters is important to demonstrate the possibilities of success of the PCMs in the thermal energy storage systems. Most PCMs are non-corrosive and chemically stable and have a high latent heat per unit weight and low vapor pressure. Their disadvantages are low thermal conductivity, high changes in volume on phase change and flammability. The life duration of PCM depends on thermal, chemical stability and corrosion resistance after number of repeated thermal cycles. The most thermal stable PCM should have a negligible change in its latent heat and melting point. Most organic PCMs investigated are paraffin, which have good thermal and chemical stability after number of thermal cycles. Paraffin is safe, reliable, predictable, less expensive and non-corrosive. This review paper is focused on various phase change materials but paraffin which qualifies as heat of fusion storage materials due to their availability in a large temperature range.

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